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CDF and D0

**Prospects for Measuring CP Violation, B_s^0 Mixing and
Rare B Decays at the Tevatron**

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Prospects for Measuring CP Violation, B_s^0 Mixing and Rare B Decays at the Tevatron

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The Fermilab Tevatron has already yielded a rich program of measurements in the b -quark sector. Here we outline the prospects for future b measurements at the Tevatron, paying particular attention to CP violation and B_s^0 mixing. In the Main Injector era, Tevatron Run II is expected to yield 2 fb^{-1} of integrated luminosity for both the CDF and DØ detectors. After Run II, even larger datasets are expected for the current collider detectors, and a dedicated B physics experiment may be constructed as well.

1. Introduction

To understand the mechanism for CP violation and test the Standard Model, the goal of b -physics experiments in the next decade will be to perform high precision measurements of quantities that can be directly related to the elements of the Cabibbo-Kobayashi-Maskawa matrix. Several experiments will contribute measurements (or limits) on CP violation in the b -sector, B_s^0 mixing and rare B hadron decays.

In the following sections we outline the prospects for performing these measurements at the Fermilab Tevatron.

2. Overview

The Fermilab Tevatron offers some unique opportunities in b -physics which are not available elsewhere. The proton-antiproton collisions at $\sqrt{s} = 2\text{ TeV}$ create $b\bar{b}$ pairs with a cross section of approximately $100\text{ }\mu\text{b}$. The b quarks can hadronize into all species, including b -baryons, and B_s and B_c mesons.

With an inelastic $p\bar{p}$ cross section which is approximately 1000 times larger than the $b\bar{b}$ cross section, it has so far been necessary to trigger on leptons from the B -hadron decays. The most common trigger paths are: $b \rightarrow \ell\nu c$ and $b \rightarrow \psi X$,

$\psi \rightarrow \mu^+\mu^-$. The signal-to-noise can be improved significantly by constructing a detector that has excellent mass resolution and that can exploit the long b lifetime ($\tau_B = 1.57 \pm 0.02\text{ ps}$, $c\tau_B = 470\text{ }\mu\text{m}$ [1].) Outer tracking detectors along with a solenoid magnetic field offer good transverse momentum (p_T) and therefore good mass resolution. Silicon microvertex detectors can resolve tracks originating from long lived particles with high efficiency.

Even though the center of mass energy of the $p\bar{p}$ system is very large, the B hadron spectrum is relatively soft. For the decay $B \rightarrow \psi K_S^0$ with a $2\text{ GeV}/c$ transverse momentum requirement on both trigger muons, the mean p_T of the B is about $10\text{ GeV}/c$, lower than that seen at LEP. This implies that tracking at low p_T (few hundred MeV) and forward tracking are both important aspects to b -physics at the Tevatron.

3. Tevatron Run II

In February of 1996, the Fermilab Tevatron completed "Run I" in which both the CDF and DØ detectors recorded approximately 110 pb^{-1} of integrated luminosity. For the upcoming "Run II", the accelerator complex will be upgraded significantly with the construction of two new components: the Main Injector and the Recycler Ring. The instantaneous luminosity is ex-

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pected to reach $\mathcal{L} = 1 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ with a 396 ns bunch spacing and eventually improve to $\mathcal{L} = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ with a 132 ns bunch spacing. The integrated luminosity for Run II is anticipated to be 2 fb^{-1} in two years of running.

4. DØ and CDF Upgrades

Both experiments are undergoing significant upgrades in order to take advantage of the major increase in luminosity foreseen for Run II. The scope of these upgrades as they apply to the b -physics program will be discussed here.

For b -physics at a hadron collider, the most important aspects of the detector are the microvertex detector, tracking chamber and high-rate trigger and data acquisition system. Additionally, it is important to be able to accurately and quickly identify leptons (e and μ) for triggering.

Both experiments are replacing completely their front-end electronics and trigger systems in order to handle the high event rates of Run II. The triggers will be pipelined and multi-staged, so that the lower trigger levels can process incoming events while higher level trigger decisions are made on previous events.

Additionally, both experiments are replacing their tracking systems. DØ is installing a 2T superconducting solenoid magnet which will surround a 4 layer silicon microvertex detector and a scintillating fiber tracker. The microvertex detector will include disks for forward tracking. The fiber tracker will cover out to 1.7 units of pseudorapidity (η) [2].

CDF is building a new gas-wire drift chamber to replace the existing central tracking chamber. The drift chamber will be able to perform particle identification using specific ionization (dE/dx). A new silicon microvertex detector is being constructed. Additional strips (located cylindrically between drift chamber and the inner silicon strips) will be installed for forward tracking. The readout chip for the silicon system is a custom chip which will allow for simultaneous digitization of data from a previous event while acquiring data into the pipeline on the current beam crossing. This "deadtimeless" mode makes way for a trigger based upon the two-dimensional distance

of closest approach (impact parameter) of tracks to the interaction point. The impact parameter information in real-time opens the possibility of triggering on B hadrons decaying to all-hadronic final states through displaced tracks [3].

5. The CKM Matrix

The Cabibbo-Kobayashi-Maskawa matrix V is a unitary matrix which rotates the electroweak eigenstates into the mass eigenstates:

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

or in the Wolfenstein parameterization:

$$\simeq \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

where $\lambda = \sin\theta_C$, sine of the Cabibbo angle. Imposing the condition of unitarity, $V^\dagger V = 1$, yields a number of relations between entries of the matrix. The most useful of these relations is:

$$V_{tb}^* V_{td} + V_{cb}^* V_{cd} + V_{ub}^* V_{ud} = 0. \quad (1)$$

This condition can be displayed graphically as a triangle in the imaginary (ρ - η) plane. Dividing the base by $V_{cd}V_{cb}^*$ to make it unit length leaves the "unitarity triangle" which is shown in Figure 1.

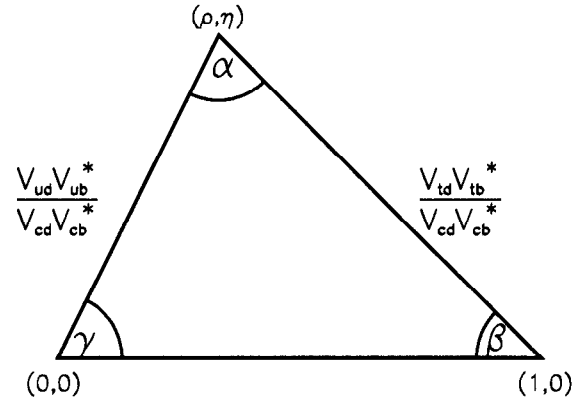


Figure 1. The unitarity triangle indicating the relationship between the CKM elements.

The program we describe here is an effort to measure both sides and all three angles of the unitarity triangle in an effort to overconstrain the CKM matrix, and hence, test the Standard Model.

6. CP Violation

CP violation manifests itself as an asymmetry in the decay rate of particle versus antiparticle. An often used example is $B^0/\bar{B}^0 \rightarrow \psi K_S^0$:

$$A_{CP} = \frac{N(\bar{B}^0 \rightarrow \psi K_S^0) - N(B^0 \rightarrow \psi K_S^0)}{N(\bar{B}^0 \rightarrow \psi K_S^0) + N(B^0 \rightarrow \psi K_S^0)}$$

which can be either a time dependant or time-integrated quantity. In the Standard Model, the CP asymmetry in this mode is proportional to $\sin 2\beta$: $A_{CP}(t) = \sin 2\beta \times \sin(\Delta m t)$, where the second term is the time-dependent evolution of B^0/\bar{B}^0 mixing. The magnitude of the CP violation term shows up as an amplitude of the mixing term.

To measure this asymmetry, the flavor of the B meson (that is, whether it contains a b -quark or a \bar{b} -quark) must be identified ("tagged") at the time of production. Since tagging algorithms are far from perfect, the true asymmetry is "diluted" by mistagging B^0/\bar{B}^0 : $A_{CP}^{obs} = D A_{CP}$, where A_{CP}^{obs} is the observed asymmetry and D is the "tagging dilution", defined as the asymmetry between the number of correct tags and incorrect tags: $D = (N_R - N_W)/(N_R + N_W)$ where $N_R(N_W)$ = number of correct (incorrect) tags. The dilution is related to the mistag rate in the following way: $D = 1 - 2w$, where w is the total fraction of incorrect tags.

As an example, if in a sample of 100 events we were able to tag 60 correctly ($N_R = 60$) and 40 incorrectly ($N_W = 40$), then the tagging dilution would be:

$$\begin{aligned} D &= (N_R - N_W)/(N_R + N_W) \\ &= (60 - 40)/(60 + 40) = 20\%. \end{aligned}$$

Relating this to the mistag rate, $D = 1 - 2w$, this example would give $w = (1 - D)/2 = (1 - 0.20)/2 = 40\%$.

The statistical error on $\sin 2\beta$ can be written as: $\delta \sin(2\beta) \approx \frac{1+x_d^2}{x_d} \frac{1}{\sqrt{\epsilon D^2 N}} \sqrt{\frac{S+B}{S}}$, where ϵ is fraction of events which can be tagged (the "tagging efficiency") and D is the dilution. The quantity x_d is the B^0/\bar{B}^0 mixing parameter, $x_d = \Delta m_d/\Gamma$, where Δm_d is the mass difference between the heavy and light B meson states and $\Gamma = \hbar/\tau$ is the average lifetime of the states. The signal (S) and background (B) comprise the sample of N total events, $N = S + B$. In order to minimize the statistical uncertainty in the measurement, the term ϵD^2 must be maximized. The dilution is the crucial factor in this equation as it comes in as D^2 . This is true because a mistagged event not only is absent from the correct tagging bin, it is also present in the incorrect tagging bin.

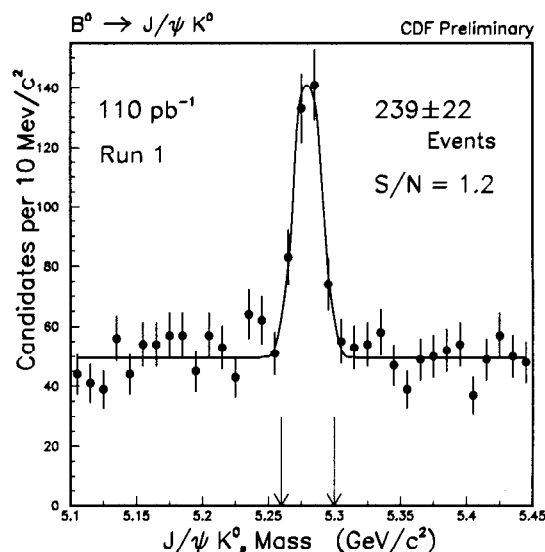


Figure 2. The CDF $B^0 \rightarrow \psi K_S^0$ mass distribution. The signal-to-noise improves to 1.7 for events contained within the acceptance of the silicon microvertex detector.

Table 1

“Effective tagging efficiencies” for different flavor tagging methods as measured by CDF. The last two columns show the the expected improvements due to the detector upgrade. Many of the increases are due to an improved acceptance.

Tagging Method	Run I	Run II projection	
	ϵD^2 (%) (measured)	ϵD^2 (%) (expected)	Relevant CDF II Upgrade
Central Muon	0.6 ± 0.1	1.0	improved muon coverage
Electron	0.3 ± 0.1	0.7	new forward cal/tracking
Same-side pion	1.5 ± 0.4	2.0	improved silicon acceptance
Jet Charge	1.0 ± 0.3	3.0	improved silicon acceptance
Opposite-side Kaon		3.0	Time-of-Flight

6.1. $\sin 2\beta$

The first measurement of CP violation in the B system is very likely to be an observation of a significant asymmetry in the decay rates into ψK_S^0 . CDF has accumulated a sample of over 200 events via a $\psi \rightarrow \mu^+ \mu^-$ trigger. The mass distribution for this sample can be seen in Figure 2. The signal-to-noise for the events in this sample is 1.2:1. For Run II, the signal-to-noise will improve due to the increase in coverage of the microvertex detector.

Improvements over the Run I yield shown in Figure 2 are expected from a) lowering the muon trigger p_T thresholds from 2.0 GeV/c to 1.5 GeV/c and b) an improved signal-to-noise from the additional microvertex detector coverage. Based upon the improvements listed here and the Run I data sample shown in in Figure 2, the Run II yield estimate is 10,000 events in 2fb^{-1} .

In addition, it is estimated that an additional 5000 events can be obtained by triggering on $\psi \rightarrow e^+ e^-$ [3].

Given this large sample of events, the statistical reach in $\sin 2\beta$ will depend largely on the “effective tagging efficiency”, ϵD^2 , as outlined in the previous section. CDF has measured these efficiencies using the Run I data sample in the context of B^0/\bar{B}^0 mixing. Table 1 shows measured and expected tagging efficiencies, along with the relevant detector upgrades which will improve the efficiencies.

For Run II, the estimated error on $\sin 2\beta$ for CDF is approximately $\delta \sin 2\beta \simeq 0.10$. this error will degrade somewhat (~ 0.13) if triggering on $\psi \rightarrow e^+ e^-$ requires too much trigger bandwidth. The estimate improves to (~ 0.08) if $\psi \rightarrow e^+ e^-$ is included along with a proposed time-of-flight system, which would significantly improve the effective tagging efficiency by introducing a “kaon” tag. It has been shown that tagging charged kaons from the b decays is a very powerful tagging method, due to the cascade $b \rightarrow c \rightarrow s$ decay [4]. The dE/dx particle identification of CDF does not offer sufficient π - K separation at low momenta ($p_T < 1.5\text{ GeV}/c$) to tag efficiently with kaons. The addition of a time-of-flight system would significantly enhance this ability.

Estimates from DØ suggest an error on $\sin 2\beta$ in the range of 0.12 – 0.15 in 2fb^{-1} .

6.2. $\sin 2\alpha$

CP violation in the decay $B^0/\bar{B}^0 \rightarrow \pi^+ \pi^-$ is related to the angle α in the unitarity triangle. This all hadronic decay mode is very challenging at a hadron collider. The small branching ratio ($< 1.5 \times 10^{-5}$ [5]) means that a significant sample can not be reconstructed opposite a $b \rightarrow \ell$ trigger.

CDF is implementing a secondary vertex trigger at Level 2 to separate hadronic B decays from inelastic (prompt) background. The information from the track trigger processor is combined with hits from the microvertex detector to measure the impact parameter of the tracks. The impact pa-

Table 2

Comparison of experimental uncertainties on $\sin 2\beta$ and $\sin 2\alpha$ from the upcoming generation of experiments. The anticipated results are listed for one year of running at design luminosity. Please note that there are a number of caveats and assumptions which go into each of these projections. The numbers are tabulated here only to give the reader a feel for not only how well each of the experiments expect to ultimately perform, but to also show the complementarity of the different experiments.

	BELLE[6]	BaBar[7]	Hera-B[8]	DØ	CDF
$\int \mathcal{L} dt (\text{fb}^{-1})$	100	30	100	1	1
$N(B \rightarrow \psi K_S^0)$	2000	1100	1500	7.5k	7.5k
$\delta(\sin 2\beta)$ ψK_S^0	0.080	0.098	0.13	0.17	0.14
all modes	0.062	0.059	0.12	0.17	0.14
$N(B \rightarrow \pi^+ \pi^-)$	650	350	800	—	5k
$BR(B \rightarrow \pi^+ \pi^-)^* (\times 10^{-5})$	1.3	1.2	1.5	—	1.0
$\delta(\sin 2\alpha)^\dagger$ $\pi^+ \pi^-$	0.147	0.20	0.16	—	0.14
all modes	0.089	0.085	0.16	—	0.14

* Assumed branching ratio.

† Assuming that contamination from penguin decays can be unfolded.

parameter resolution of this device is approximately $35 \mu\text{m}$ and the impact parameter information will be supplied to the trigger decision processor in less than $15 \mu\text{s}$. This device requires beam position stability both during the store and from store-to-store. Real time beam position information will be fed back to the accelerator so that the position of the interaction region can be maintained over the course of the store.

Based upon existing data, it is estimated that an impact parameter cut of $100 \mu\text{m}$ will yield a rejection factor of about 1000. The bandwidth challenge for the trigger is at Level 1, where no impact parameter information is available. Here a two-track trigger with kinematic cuts will yield a rate of 16 kHz. That rate is reduced to 20 Hz at Level 2 with the impact parameter trigger.

After triggering on the $B \rightarrow$ two-track final state, the $B \rightarrow \pi^+ \pi^-$ final state must be isolated from the physics backgrounds from $B^0 \rightarrow K\pi$, $B_s^0 \rightarrow K\pi$ and $B_s^0 \rightarrow KK$. The mass resolution of the tracking system ($20 \text{ MeV}/c^2$ for $B \rightarrow \pi\pi$) is not sufficient to isolate the signal from these backgrounds. In particular, the $B_s^0 \rightarrow KK$ final state reflects directly under the $B^0 \rightarrow \pi\pi$ mass

peak when the two kaons are assumed to be pions.

To further isolate the $B \rightarrow \pi^+ \pi^-$ signal from these physics background, π - K separation is required. CDF will use dE/dx information from the central tracking chamber to separate the signal from the backgrounds on a statistical (not event-by-event) basis. The system will yield $> 1\sigma$ π - K separation for $p_T > 2 \text{ GeV}/c$. The proposed time-of-flight system, although very useful for flavor tagging, will not be capable of π - K separation at these higher momenta.

The yield estimate is 10k events in 2 fb^{-1} . Including all possible tagging modes, the estimated error on $\sin 2\alpha$ is approximately 0.10. It should be noted that this estimate assumes that the magnitude of penguin contamination can be estimated from a combination of theoretical and experimental inputs. If this is not the case, then it is very unlikely that the magnitude of the asymmetry will yield a precision measurement of $\sin 2\alpha$.

6.3. Comparing with Projections from Other Experiments

Several experiments will be collecting data in the period 1999-2001. Two e^+e^- B -factories

at SLAC(BaBar) and KEK(BELLE), as well as a internal target production experiment at HERA(HERA-B) all intend to make many measurements in the B sector, including measurements of $\sin 2\beta$ and $\sin 2\alpha$. Table 2 shows the expected reach of each of these experiments in approximately one year of running at the design luminosity of each machine.

It is interesting to note that although the expected reach is similar for all of the experiments, the Tevatron measurements are in marked contrast to the measurements at BELLE, BaBar and HERA-B. Those experiments will have significantly smaller data samples but significantly better tagging efficiencies. This, along with different modes of production will allow all of these measurements to complement one another. This also points out how crucial flavor tagging is at the Tevatron.

Please also note that all of these experiments plan a rich program in B physics beyond the measurements of these two angles in the unitarity triangle. Also, CLEO-III will be running during this period, and will produce a large number of measurements of their own, including information which will help unfold the penguin contributions to $B \rightarrow \pi^+ \pi^-$ [9].

7. Measuring $|V_{td}/V_{ts}|$

7.1. Time Dependant B_d^0/\bar{B}_d^0 Mixing

An observation of B_d^0/\bar{B}_d^0 mixing would lead to a measurement of the ratio of CKM elements V_{td} and V_{ts} in the following way:

$$\frac{x_s}{x_d} = \frac{(m_{B_s} \eta_{QCD}^{B_s} B_{B_s} f_{B_s}^2)}{(m_{B_d} \eta_{QCD}^{B_d} B_{B_d} f_{B_d}^2)} \left| \frac{V_{ts}}{V_{td}} \right|^2 = (1.3 \pm 0.2) \left| \frac{V_{ts}}{V_{td}} \right|^2,$$

where $x_i = \Delta m_i / \Gamma_i$ ($i = d, s$); m_{B_i} are the meson masses; B_{B_i} are B meson bag parameters; f_{B_i} are B meson weak decay constants and $\eta_{QCD}^{B_i}$ are QCD corrections of order unity.

B_d^0/\bar{B}_d^0 mixing has been well measured at the Tevatron and LEP. Figure 3 shows the CDF measurement of B_d mixing using the same-side tagging method. In this analysis, lepton triggered events are reconstructed in the $\ell D(D^*)$ mode. The flavor of the B at the time of decay is es-

tablished from the charm (D) decay, while the flavor at production is inferred from the charge correlation of tracks near the B hadron with the flavor of the b -quark. This "same-side" correlation may arise through the fragmentation process or through excited (B^{**}) states [10].

The current world average on the value of x_d is 0.75 ± 0.04 [1]. The existing limits on x_s are rather high, $x_s > 10.4$ [11], so we know that the oscillation is very fast. This renders a time integrated approach unworkable.

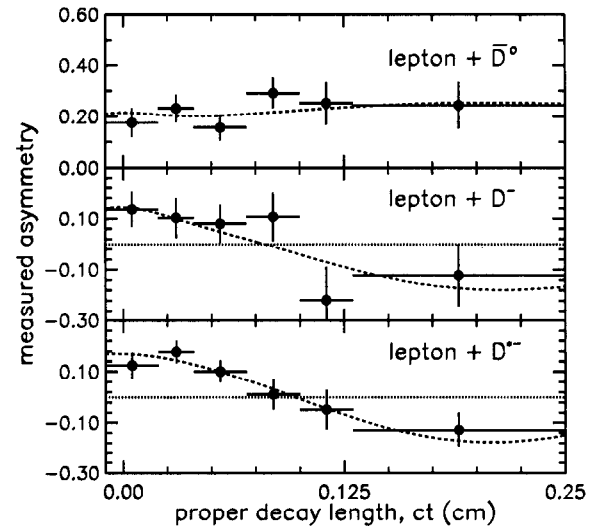


Figure 3. Time dependant B_d^0/\bar{B}_d^0 mixing as measured from $B^0/\bar{B}_d^0 \rightarrow \ell^\pm \nu D^\mp (D^{*\mp})$. The top plot shows the B - π charge correlation in the B^\pm sample, where no mixing takes place. The middle and bottom plots show the correlation for B^0/\bar{B}_d^0 events. The oscillatory behavior can be seen. The result, $\Delta m_d = 0.45 \pm 0.07 \text{ ps}^{-1}$ is competitive with other single measurements of B_d mixing.

B_s mixing will be studied using both semileptonic and fully reconstructed decay modes. Semileptonic decays which include $B_s \rightarrow D_s \ell \nu$ and $B_s \rightarrow \phi \ell \nu X$ have the advantage of large statistics, but the drawback of the missing neu-

trino leading to poor $\beta\gamma$ (boost) resolution. The proper decay time resolution becomes the limiting factor. The ultimate x_s reach through this mode at the Tevatron is approximately 15.

Note that for a measurement of time dependant or time integrated mixing, the flavor of the B hadron must be identified at both the time of production and the time of decay. In the case of $B_s \rightarrow D_s X$, the decay of the D_s into $\phi\pi$, K^*K or $K_s^0 K$ uniquely identifies the flavor of the B_s^0/\bar{B}_s^0 at the time of decay.

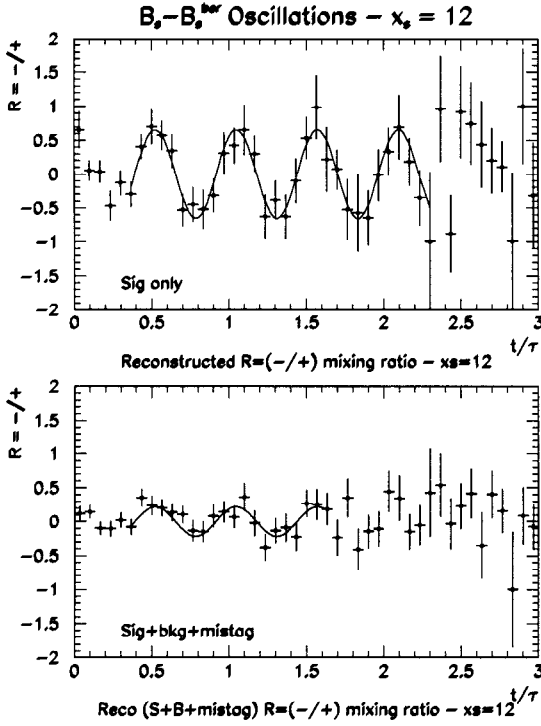


Figure 4. DØ time dependant B_s^0/\bar{B}_s^0 mixing simulation with $x_s = 12$. The top plot shows the $B_s \rightarrow D_s\pi$ signal only. The bottom plot includes background and mistags. A clear oscillation can still be resolved.

Fully reconstructed decays offer the advantage of much better boost resolution over the semilep-

tonic modes. The drawback is that decay modes without leptons in the final state have not yet been triggered upon (and isolated) at a hadron collider. This means that the $B_s \rightarrow D_s\pi(3\pi)$ must be either reconstructed opposite a trigger $B \rightarrow \ell$ or else an impact parameter trigger must be used to attempt to separate the all hadronic final state. In either case, the statistics of the fully reconstructed mode will be significantly reduced from the semileptonic modes. However, studies performed by both DØ and CDF have shown that the ultimate reach in x_s will be better for the fully reconstructed mode than it will be for the semileptonic mode. Figure 4 shows the results of a DØ study performed looking at the fully reconstructed $D_s\pi/D_s3\pi$ final state opposite a lepton trigger. The lepton is used to tag the initial flavor of the B_s .

7.2. Lifetime Difference

The ultimate reach in time dependant B_s^0 mixing in Run II is $x_s \lesssim 20$. In the event that x_s is larger than this, it will be possible to directly measure two different lifetime components of a B_s^H (heavy) and B_s^L (light) mass eigenstates in an analogous fashion to the neutral kaon system.

In the standard model [12]:

$$\Delta\Gamma_{B_s}/\Delta m_{B_s} = -\frac{3}{2}\pi \frac{m_b^2}{m_t^2} \frac{\eta_{QCD} \Delta\Gamma_{B_s}}{\eta_{QCD} \Delta m_{B_s}},$$

where $\Delta\Gamma = \Gamma_H - \Gamma_L$ is the lifetime difference between the two CP eigenstates. The ratio $\Delta\Gamma_{B_s}/\Delta m_{B_s}$ contains no CKM elements and the uncertainty on this ratio depends only upon QCD corrections which are of order unity. Therefore, as $\Delta m_s(x_s)$ gets larger and becomes inaccessible, the lifetime difference grows and becomes accessible.

In current event samples, the two main sources of B_s decays are the $D_s\ell$ and $\psi\phi$ final states. The $D_s\ell$ sample is expected to be a 50:50 CP even/CP odd mixture. Therefore, it will be possible to directly fit the lifetime distribution for two lifetime components. Additionally, the $B_s \rightarrow \psi\phi$ is expected to be predominantly CP even. Therefore a comparison of the lifetime in that mode to the lifetime measured in the inclusive $D_s\ell$ sample will

show a difference. If the $\psi\phi$ final state is not a pure CP eigenstate, the CP components to that state will be unfolded via a transversity analysis [13]. Then each CP component in $\psi\phi$ can be fit for a lifetime separately. As discussed in the previous section, additional B_s decay modes are expected to be included in the Run II analyses.

8. B_c , Radiative and Rare Decays

8.1. B_c

The B_c is an interesting $q\bar{q}'$ system because of the two unequal heavy quark masses. Searches have been performed in the following decay modes:

- $B_c \rightarrow \psi\pi$
- $B_c \rightarrow \psi\ell\nu$ (tri-lepton mode.)

If the B_c is not observed in the data from collider Run I, we will have to await Run II to observe and study the B_c . Measurement of the B_c production cross section, mass and lifetime are particularly interesting.

It should be noted that although B_c decay modes involving the ψ are substantial, the dominant decay mode is expected to be the $c \rightarrow s$ transition, giving $B_c \rightarrow B_s X$. Given enough statistics, the B_c could become a very powerful flavor tagging tool for B_s mixing. As an example, if a sample of $B_c^\pm \rightarrow B_s \pi^\pm$ could be isolated, the flavor of the B_s would be unambiguously tagged at the time of production by the charge of the associated pion from the B_c decay.

8.2. Radiative Decays

In the absence of long distance effects, $|V_{td}/V_{ts}|$ can be probed via $B \rightarrow \rho\gamma$ and $B \rightarrow K^*\gamma$. CDF installed a dedicated trigger for radiative B decays for the latter part of Run I. With 23 pb^{-1} of data taken with this trigger a limit of $BR(B^0 \rightarrow K^{*0}\gamma) < 2.9 \times 10^{-4}$ was established [14]. If the rates are near Standard Model expectations, approximately 2500 $K^*\gamma$ events should be seen. Additionally, a signal should be seen in the decay mode $B_s \rightarrow \phi\gamma$.

Radiative decays detected via photon conversion will also be pursued. The conversion rate is

small (few percent) and depends upon the amount of material in the inner detector regions. The advantage in using conversions arises from *a*) lower trigger thresholds for electrons versus photons and *b*) much improved π^0 rejection.

8.3. Rare B Decays

As in the kaon system, rare decays are sensitive to physics beyond the Standard Model. Both CD-F and DØ will be well suited to search for (and likely observe some) of the following rare decays:

- $B^+ \rightarrow \mu^+\mu^-K^+$
- $B^0 \rightarrow \mu^+\mu^-K^{*0}$
- $B^0 \rightarrow \mu^+\mu^-$
- $B_s^0 \rightarrow \mu^+\mu^-$.

Good muon coverage and mass resolution enhance the reach of searches in the dimuon modes. Based upon Standard Model rates, it is likely that the decay modes $\mu^+\mu^-K^+$ and $\mu^+\mu^-K^{*0}$ will be observed. The Standard Model expectations for $B^0 \rightarrow \mu^+\mu^-$ and $B_s^0 \rightarrow \mu^+\mu^-$ are well below the expected Run II reach. This means that any signal seen in these modes will be an immediate signal of new physics.

9. Beyond Tevatron Run II

By the year 2002-2003, CP violation will very likely have been observed in the B system in several experiments. However, it is very unlikely that sensitivity of the measurements will be such that the true nature of CP violation in the B system is understood.

Since all of the measurements outlined here (and much of the high- p_T Tevatron program as well) will still be statistically limited after 2 fb^{-1} of data, it makes sense to run for more data. Tevatron "Run III" would include higher instantaneous luminosity ($10^{32} \lesssim \mathcal{L} \lesssim 10^{33} \text{ cm}^{-2}\text{s}^{-1}$) and integrated luminosities in the range of 10 to 30 fb^{-1} .

To take advantage of this high luminosity for B physics, the existing detectors would have to be upgraded significantly. These upgrades would likely include: new vertexing (to improve and replace radiation damaged silicon detectors), new

electronics (to handle higher event rates), finer tracking segmentation (to handle higher occupancies), and improved particle identification.

In addition to the CDF and DØ detectors, there is a proposal for the BTeV experiment, a dedicated B physics experiment which would run in the C0 interaction region [15]. The BTeV experiment would feature a forward geometry, strong tracking and vertex detection and good particle identification. All of these considerations will be optimized for doing high precision B measurements at the Tevatron.

10. Conclusion

The outlook for B physics in the near future is very bright. Several experiments will produce measurements which will significantly constrain the CKM matrix and further our understanding of CKM physics and CP violation. Both CDF and DØ will play an active roll in these CP violation measurements, particularly in the decay $B^0/\bar{B}^0 \rightarrow \psi K_s^0$.

The Tevatron program will also yield important measurements in the B_s^0 system with either a direct or indirect measure of B_s^0 mixing, as well as study of the B_c system. These mesons will not be accessible at the $\Upsilon(4s)$ B -factories.

Highlights of the b physics program at the Tevatron in Run II will very likely include:

- an observation of CP violation in the B system
- direct or indirect measurement of Δm_s
- observation and study of the B_c meson
- observation of "rare" B -decays
- stringent constraints on the CKM matrix and precision tests of the Standard Model.

Beyond Run II, even larger data samples are anticipated to further reduce the errors on these measurements. In addition, the potential for a dedicated heavy flavor detector will lead to significant further advances and understanding and test of the CKM matrix, CP violation and the Standard Model.

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